The Experiment of the Weather Monitoring

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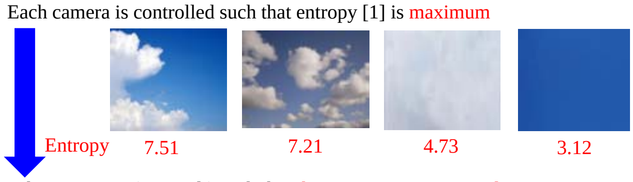
Outline

Approach

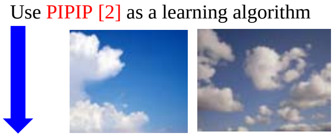
Monitoring

Each camera is controlled such that entropy [1] is maximum



Choose action (Pan, Tilt) such that the entropy is maximized using potential game [2]

Use PIPIP [2] as a learning algorithm



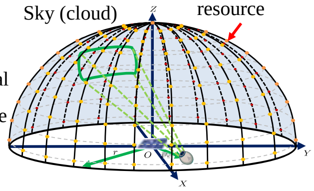
We can know the size and shape of cloud

PTZ camera

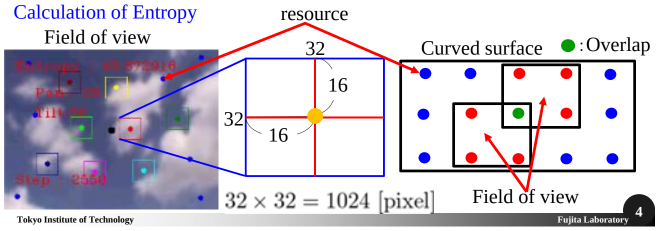
Approach

Scenario

1. Suppose that sky is a curved surface
2. Arrange resources at an equal interval
3. Compute the entropy around resource
4. Move camera such that the entropy is maximized



Calculation of Entropy



Application of Potential Game

Potential Function

$$\phi(a) = \sum_{i \in \mathcal{V}} \left(\sum_{r_i \in R_i} H(r_i) - \sum_{r_l \in R_i \cap R_{-i}} H(r_l) \right)$$

The sum of entropy around resources camera i is using

The sum of entropy around overlapping resources

Utility Function

$$U_i(a) = \sum_{r_i \in R_i} H(r_i) - \sum_{r_l \in R_i \cap R_{-i}} H(r_l)$$

$\mathcal{V}$: A set of cameras

R_i : A set of resources that camera i uses

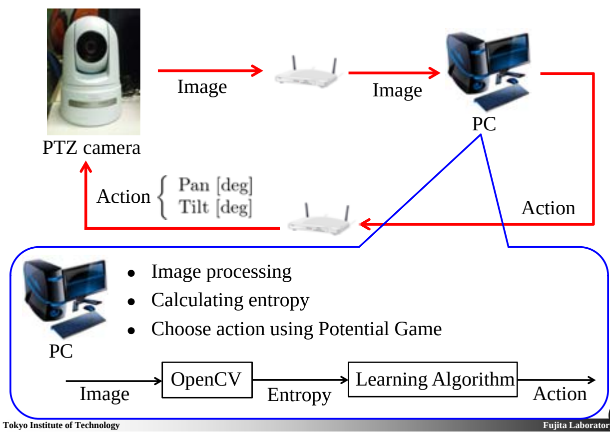
$i \in \mathcal{V} \quad \mathcal{V} = \{1, \cdots, n\}$

R_{-i} : A set of resources that cameras (except for camera i) use

$$R_{-i} = \bigcup_{j \neq i} R_j \quad j \in \mathcal{V}$$

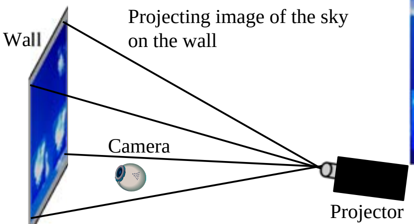
$H(r)$: Entropy around resource r

Experimental System



Experiment

Indoor

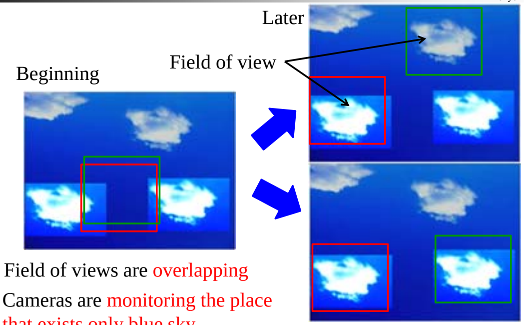


Image

Outdoor

Experiment in the roof

Experiment (Indoor)



Field of views are overlapping

Cameras are monitoring the place that exists only blue sky

Cameras are monitoring the place that exists cloud and blue sky

	Only cloud or blue sky	Existing cloud and blue sky
Entropy	～ About 20	About 23 ～ About 39

Settings (Indoor)

Agent

$N = 2$ (PTZ camera)

Action

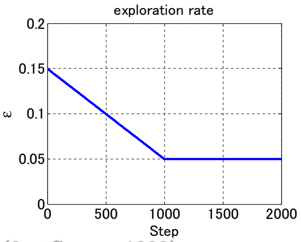
$a_i = (\text{Pan}, \text{Tilt})$ [deg] $i = \{1, \cdots, N\}$

Restricted Action Set

$\mathcal{R}_i(a_i) = \{a_i + 5(b_1, b_2) | b_1 \in \{-1, 0, 1\}, b_2 \in \{-1, 0, 1\}\}$

$-35° \leq \text{Pan} \leq 35°$

$20° \leq \text{Tilt} \leq 45°$



Learning Algorithm

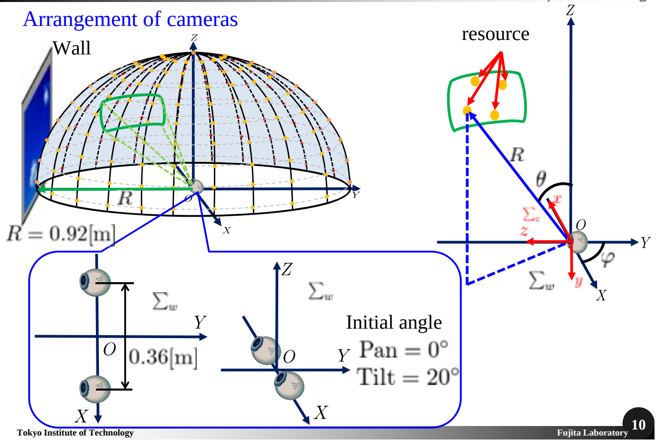
PIPIP

Exploration Rate

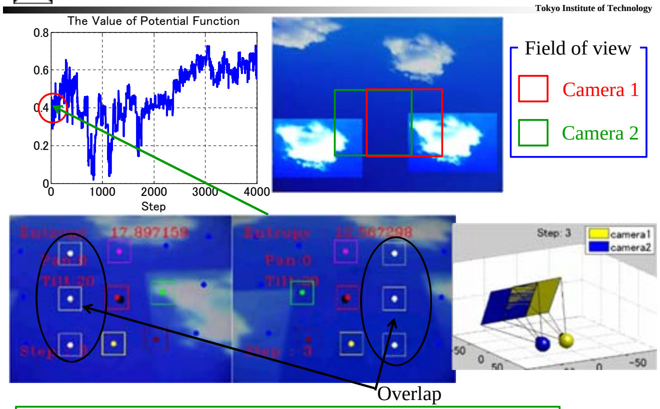
$$\varepsilon = \begin{cases} 0.15 - 0.0001 \times \text{Step} & (0 \leq \text{Step} < 1000) \\ 0.05 & (1000 \leq \text{Step}) \end{cases}$$

Settings (Indoor)

Arrangement of cameras

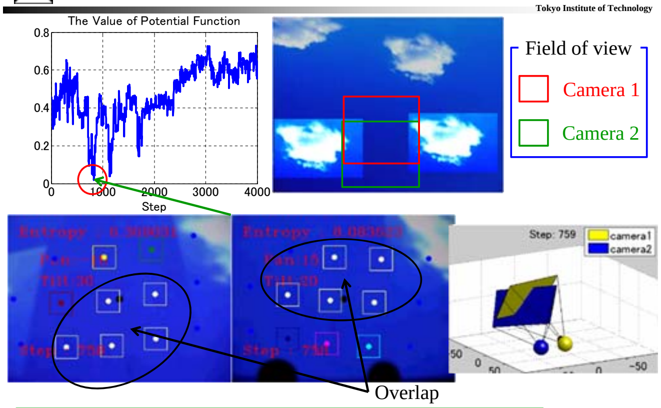


Results (Indoor)



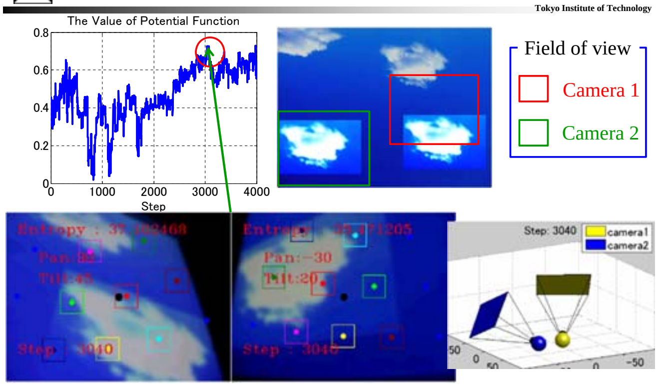
Camera 1 (left) Entropy 17.89 Camera 2 (right) Entropy 12.56

Results (Indoor)



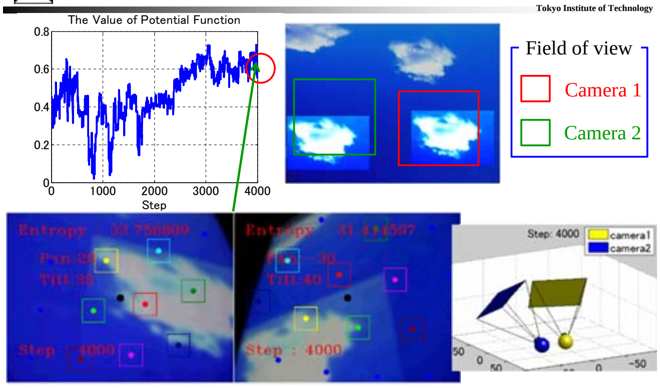
Camera 1 (left) Entropy 6.36 Camera 2 (right) Entropy 8.08

Results (Indoor)



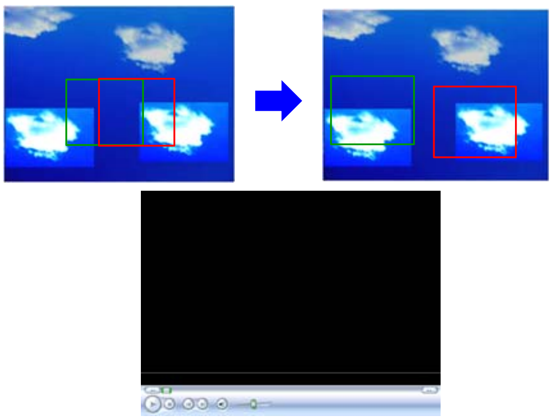
Camera 1 (left) Entropy 37.10 Camera 2 (right) Entropy 35.47

Results (Indoor)

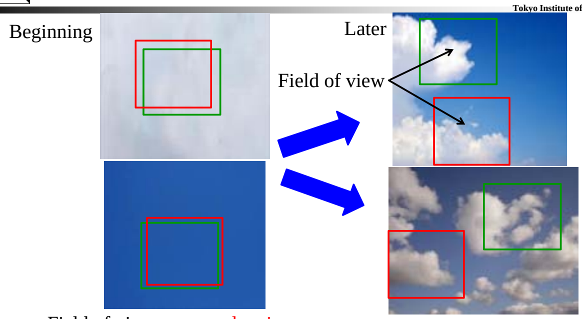


Camera 1 (left) Entropy 33.75 Camera 2 (right) Entropy 31.41

Results (Indoor)



Experiment (Outdoor)



Field of views are overlapping
Cameras are monitoring the place that exists only blue sky or cloud

Cameras are monitoring the place that exists cloud and blue sky

	Only cloud or blue sky	Existing cloud and blue sky
Entropy	About 18 ～ About 30	About 33 ～ About 46

Settings (Outdoor)

Agent

$N = 4$ (PTZ camera)

Action

$a_i = (\mathrm{Pan}, \mathrm{Tilt})\ [\mathrm{deg}] \quad i = \{1, \cdots, N\}$

Restricted Action Set

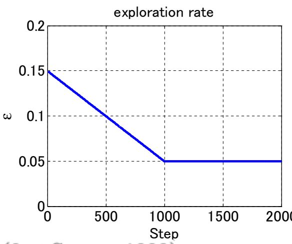
$$\mathcal{R}_i(a_i) = \{a_i + 5(b_1, b_2) | b_1 \in \{-1, 0, 1\}, b_2 \in \{-1, 0, 1\}\}$$

$$-40^\circ \leq \mathrm{Pan} \leq 40^\circ$$

$$30^\circ \leq \mathrm{Tilt} \leq 90^\circ$$

Learning Algorithm

PIPIP

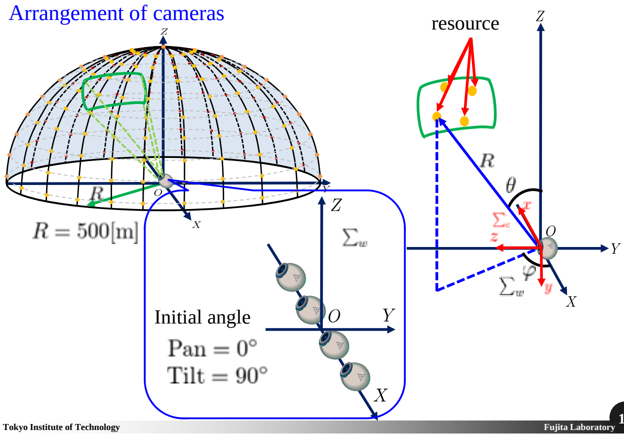


Exploration Rate

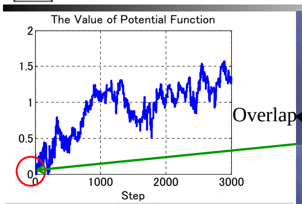
$$\varepsilon = \begin{cases} 0.15 - 0.0001 \times \mathrm{Step} & (0 \leq \mathrm{Step} < 1000) \\ 0.05 & (1000 \leq \mathrm{Step}) \end{cases}$$

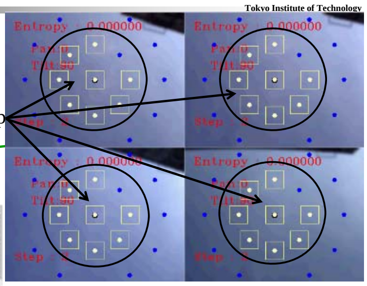
Settings (Outdoor)

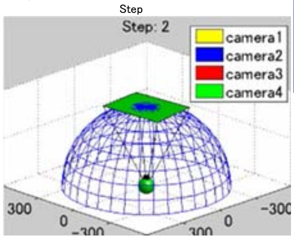
Arrangement of cameras



Results (Outdoor)

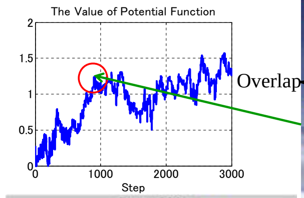


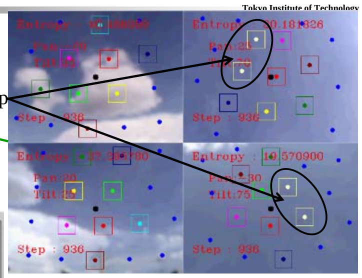


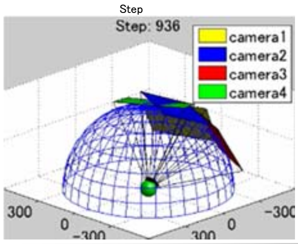


Camera 1 (upper left) Entropy 0.00
Camera 2 (upper right) Entropy 0.00
Camera 3 (lower left) Entropy 0.00
Camera 4 (lower right) Entropy 0.00

Results (Outdoor)

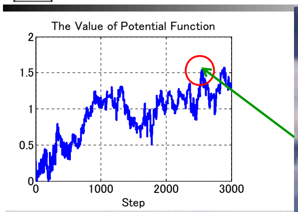


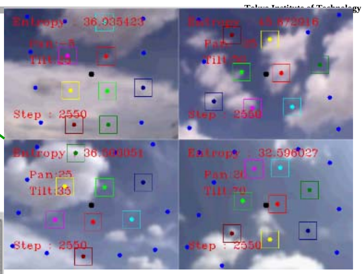


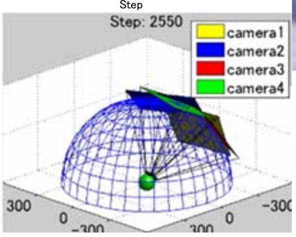


Camera 1 (upper left) Entropy 40.46
Camera 2 (upper right) Entropy
Camera 3 (lower left) Entropy 37.28
Camera 4 (lower right) Entropy 19.57

Results (Outdoor)

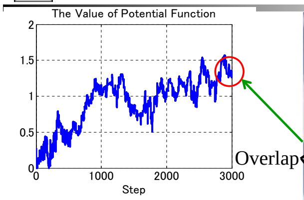


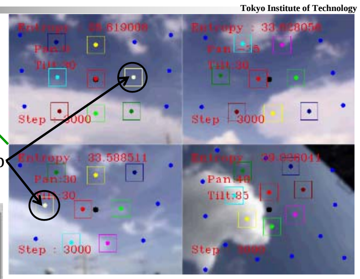


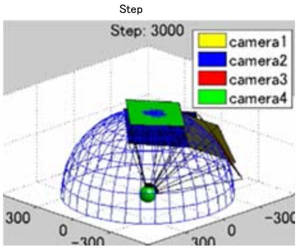


Camera 1 (upper left) Entropy 36.93
Camera 2 (upper right) Entropy 45.67
Camera 3 (lower left) Entropy 36.50
Camera 4 (lower right) Entropy 32.59

Results (Outdoor)

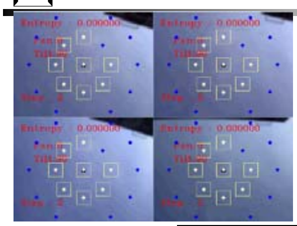


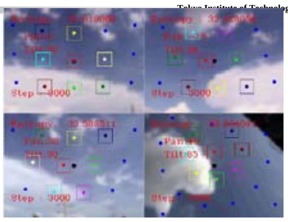


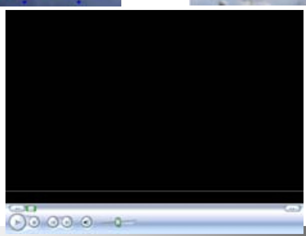


Camera 1 (upper left) Entropy 26.61
Camera 2 (upper right) Entropy 33.62
Camera 3 (lower left) Entropy 33.58
Camera 4 (lower right) Entropy 39.02

Results (Outdoor)





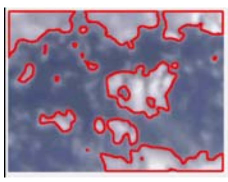


Future Works

- Utility Design
- Cloud Detection [3]

The pixel Red-Blue Ratio (RBR)

The RBR of a Clear Sky Library (CSL)



- Cloud Motion [4, 5]

Cloud Motion Vectors

Numerical Weather Prediction (NWP) Model

Analysis of satellite imagery

References

[1] Y. Zhang, M. Rotea, N. Gans, “Sensors Searching for Interesting Things: Extremum Seeking Control on Entropy Maps,” *the 50th IEEE Conference on Decision and Control and European Control Conference*, Orlando, Florida, USA, Dec. 14th, 2011.

[2] T. Goto, T. Hatanaka and M. Fujita, “Payoff-based Inhomogeneous Partially Irrational Play for Potential Game Theoretic Cooperative Control of Multi-agent Systems,” (available at arXiv:1107.4838), 2011.

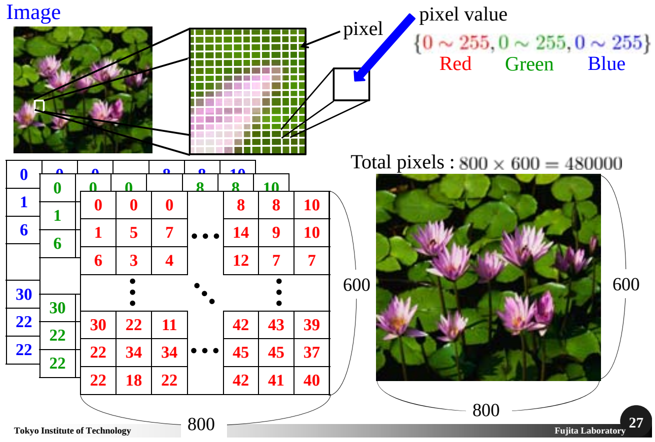
[3] M. S. Ghonima, B. Urquhart, C. W. Chow, J. E. Shields, A. Cazorla and J. Kleissl, “A method for cloud detection and opacity classification based on ground based sky imagery,” *Atmospheric Measurement Techniques Discussions*, Vol. 5, No. 4, pp. 4535-4569, 2012.

[4] C. W. Chow, B. Urquhart, M. Lave, A. Dominguez, J. Kleissl, J. E. Shields and B. Washom, “Intra-hour forecasting with a total sky imager at the UC San Diego solar energy testbed,” *Solar Energy*, Vol. 85, No. 11, pp. 2881-2893, 2011.

[5] V. Thottathil Jayadevan, V. P. A. Lonij, J. J. Rodriguez, A. D. Cronin, “Forecasting solar power intermittency using ground-based cloud imaging,” *World Renewable Energy Forum*, 2012.

Appendix

Entropy



Entropy

Ex) Pixel value of red

0	0	0		8	8	10
1	5	7	…	14	9	10
6	3	4		12	7	7
⋮			⋱		⋮	
30	22	11		42	43	39
22	34	34	…	45	45	37
22	18	22		42	41	40

600 (rows), 800 (columns)

Total pixels $800 \times 600 = 480000$

Probability $p(x)$

$$p(x) = \frac{\text{The number of pixel value x}}{\text{Total pixels}}$$

$$p(0) = \frac{\text{The number of pixel value 0}}{\text{Total pixels}}$$

$$p(1) = \frac{\text{The number of pixel value 1}}{\text{Total pixels}}$$

⋮

$$p(255) = \frac{\text{The number of pixel value 255}}{\text{Total pixels}}$$

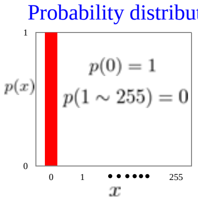
Entropy

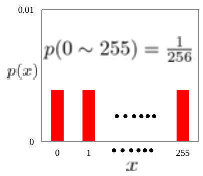
$$H(X) = -\sum_{x \in X} p(x) \log_2 p(x)$$

- Calculate entropy of red , green and blue
- Take an average

Entropy

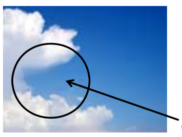
Probability distribution





low $H(X) = 0$ ← Entropy → high $H(X) = 8$

The more kind of color is , the larger entropy is



The entropy is large

Entropy

$$H(X) = -\sum_{x \in X} p(x) \log_2 p(x)$$

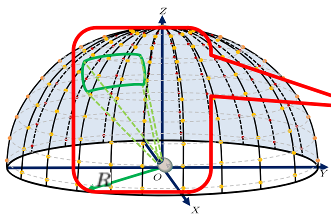
Arrangement of resources

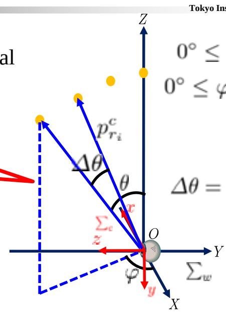
Arrange resources at an equal interval

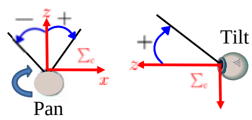
$0^\circ \le \theta \le 90^\circ$

$0^\circ \le \varphi \le 360^\circ$

$\Delta\theta = 10[\text{deg}]$







ψ_{pan} : Angle of pan rotation

ψ_{tilt} : Angle of tilt rotation

Arrangement of resources

Second row $\Delta\varphi = 45°$

Third row $\Delta\varphi = 30°$

Fourth row $\Delta\varphi = 22.5°$

⋮ ⋮

Ninth row $\Delta\varphi = 9°$

View from the top